

CLAIMS

What is claimed is:

- 1 1. A method for correcting signals received from an earth formation using a
2 Nuclear Magnetic Resonance (NMR) tool into a borehole in said earth formation,
3 the method comprising:
 - 4 (a) exciting said earth formation with a first pulse sequence having a first
5 recovery time;
 - 6 (b) exciting said earth formation with a plurality of additional pulse sequences
7 having a second recovery time less than said first recovery time;
 - 8 (c) determining from spin echo signals resulting from said additional pulse
9 sequences an estimate of a non-formation signal; and
 - 10 (d) correcting spin echo signals resulting from said first pulse sequence using
11 said estimate and obtaining corrected spin echo signals.
- 12
- 1 2. The method of claim 1 wherein at least one of said additional pulse sequences has
2 a duration less than a duration of said first pulse sequence.
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- 1 3. The method of claim 1 wherein said second recovery time corresponds to partial
2 recovery of nuclear spins in said earth formation.
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- 1 4. The method of claim 1 wherein said additional pulse sequences comprise clay
2 bound water (CBW) sequences.
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- 1 11. The method of claim 8 wherein said non-formation signal comprises a ringing
2 from a refocusing pulse.
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 - 1 12. The method of claim 8 wherein said non-formation signal comprises a ringing
2 from an excitation pulse.
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 - 1 13. The method of claim 11 wherein estimating said ringing from said refocusing
2 pulse further comprises:
 - 3 (i) separately estimating a ringing from each one of said plurality of phase
4 alternated pairs;
 - 5 (ii) forming a vector sum of said separate estimates.
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 - 1 14. The method of claim 12 wherein estimating said ringing from said excitation
2 pulse further comprises:
 - 3 (i) separately estimating an echo signal from each one of said plurality of
4 phase alternated pairs; and
 - 5 (ii) forming a vector sum of said separate estimates of said echo signal.
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 - 1 15. The method of claim 1 further comprising processing said corrected spin echo
2 signals for determining at least one of (i) a T_2 distribution, (ii) total porosity, (iii)
3 bound volume irreducible, (iv) a T_1 distribution, (v) clay bound water, and, (vi)

1 16. The method of claim 1 further comprising conveying said NMR tool into said
2 earth formation on one of (i) a wireline, (ii) a drilling tubular, and, (iii) a
3 slickline.

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1 17. The method of claim 1 further comprising:

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1 18. The method of claim 17 further comprising:

2 (A) comparing said estimate and said additional estimate of said non-
3 formation signal; and
4 (B) using a result of said comparison as an indication of a change in said earth
5 formation between positions of said NMR tool at excitation with said first
6 and second pulse sequences.

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1 19. An apparatus for conducting logging operations in a borehole in an earth
2 formation, the apparatus comprising:

3 (a) a magnet on a Nuclear Magnetic Resonance (NMR) tool for polarizing
4 nuclear spins in a region of interest in the earth formation;

5 (b) an antenna on the NMR tool for:

6 (A) exciting said earth formation with a first pulse sequence

7 having a first recovery time;

8 (B) exciting said earth formation with a plurality of additional

9 pulse sequences having a recovery time less than said first

10 recovery time;

11 (c) a processor for

12 (C) determining from spin echo signals resulting from said

13 additional pulse sequences an estimate of a non-formation signal, and

14 (D) correcting spin echo signals resulting from said first pulse

15 sequence using said estimate and obtaining corrected spin echo

16 signals.

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1 20. The apparatus of claim 19 wherein said additional pulse sequences comprise
2 clay bound water (CBW) sequences.

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1 21. The apparatus of claim 19 wherein said additional pulse sequences have
2 durations less than 40 ms.

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1 22. The apparatus of claim 19 wherein said first pulse sequence and said additional
2 pulse sequences comprise CPMG sequences.

1 23. The apparatus of claim 19 wherein said first pulse sequence and said
2 additional pulse sequences comprise modified CPMG sequence having a tip angle
3 of a refocusing pulse that is less than 180°.

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1 24. The apparatus of claim 19 wherein said additional pulse sequences comprise
2 pulse sequences having a plurality of pairs of phase alternated pairs (PAP) of
3 pulse sequences.

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1 25 The apparatus of claim 24 wherein said plurality of pairs of PAP sequences
2 have a specified phase relationship to each other.

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1 26 The apparatus of claim 24 wherein the number of said pairs of PAP sequences
2 nf , frequency shift between said pairs of PAP sequences δf are related
3 according to:

4
$$nf \cdot \delta f = \frac{m}{t}$$

5 where m is any integer that is not a multiple of nf .

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1 27 The apparatus of claim 24 wherein said non-formation signal comprises a ringing
2 caused by a refocusing pulse.

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1 28 The apparatus of claim 24 wherein said non-formation signal comprises a ringing
2 caused by an excitation pulse.

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1 29 The apparatus of claim 24 wherein said processor estimates said ringing caused
2 by said refocusing pulse by:

- 3 (i) separately estimating a ringing from each one of said plurality of phase
4 alternated pairs;
5 (ii) forming a vector sum of said separate estimates.

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1 30 The apparatus of claim 25 wherein said processor estimates said ringing caused
2 by said excitation pulse by:

- 3 (i) separately estimating an echo signal from each one of said plurality of
4 phase alternated pairs; and
5 (ii) forming a vector sum of said separate estimates of said echo signal.

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1 31 The apparatus of claim 21 wherein said processor further determines from said
2 corrected spin echo signals at least one of (i) a T_2 distribution, (ii) total porosity,
3 (iii) bound volume irreducible, (iv) bound water movable, (v) clay bound water,
4 and, (vi) a T_1 distribution.

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1 32. The apparatus of claim 19 further comprising a conveyance device for
2 conveying said NMR tool into said borehole, said conveyance device selected
3 from (i) a wireline, (ii) a drilling tubular, and, (iii) a slickline

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1 33. The apparatus of claim 15 wherein said transmitter further excites said earth
2 formation with a second pulse sequence having a recovery time substantially equal

3 to said first recovery time, said second pulse sequence forming a phase alternated
4 pair with said first pulse sequence; and wherein said processor further
5 determines from spin echo signals resulting from said first and second pulse
6 sequences an additional estimate of said non-formation signal.

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- 1 34. The apparatus of claim 33 wherein said processor further:
- 2 (i) compares said estimate and said additional estimate of said non-
3 formation signal; and
- 4 (ii) provides an indication of a change in said earth formation between
5 positions of said NMR tool at excitation with said first and second pulse
6 sequences.

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